WORKING-FLUID MOVING DEVICE

BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates to a working-fluid moving device for moving a working fluid, the device being suitable for use as, for example, a switching device for changing over electric paths or optical paths, a sensor for detecting the position of a pressing portion or the like, or a drive source for driving a cylinder or the like.

Description of the Related Art:

Conventionally, for example, a device 100 having the structure shown in FIG. 14 is known as this kind of working-fluid moving device. The device 100 includes a channel 101 having a rectangular cross section; a first working fluid (moving body) 102 housed in the channel 101; a second working fluid 103 housed in the channel 101 and exhibiting better wettability to the inner wall of the channel 101 than the first working fluid 102; and a pair of pump chambers 104 and 105 disposed at opposite ends of the channel 101. The device 100 is adapted to move the first working fluid 102 rightward in FIG. 14 through feed of the second working fluid 103 into the channel 101 from the pump chamber 104 and to move the first working fluid 102 leftward in FIG. 14 through feed of the second working fluid 103 into the channel 101 from the pump chamber 105.

In this case, since the first working fluid 102 is inferior to the second working fluid 103 in wettability to the inner wall of the channel 101, as shown in FIG. 15 that is a sectional view of the channel 101 cut by a plane along line 1-1 of FIG. 14, very small spaces SP are formed between the first

working fluid 102 and the inner wall surface of the channel 101 at corner portions. Thus, when causing the first working fluid 102 to move, the second working fluid 103 passes through the spaces SP.

Hence, in order to move the first working fluid 102 by a predetermined distance, either the pump chamber 104 or the pump chamber 105 must feed the second working fluid 103 into the channel 101 in an amount equivalent to the total of the volume of the second working fluid 103 to be displaced at the time of movement of the first working fluid 102 and the volume of the second working fluid 103 passing through the spaces SP, while the other pump chamber 104 or 105 must remove the second working fluid 103 from the channel 101 in an amount equal to that of the second working fluid 103 to be fed into the channel 101.

Thus, the device 100 involves a problem that, when the first working fluid 102 is to be moved at high speed, a large amount of the second working fluid 103 must be fed and removed within a short period of time; however, the pump chambers 104 and 105 may fail to move the first working fluid 102 at a required high speed, if their discharge performances are insufficent.

In the device 100, the volume of the pump chamber 104 or 105 is changed so as to feed the second working fluid 103 into the channel 101, thereby moving the first working fluid 102. Thus, the driving force of the pump chamber 104 or 105 is not exerted directly on the first working fluid 102, but is indirectly transmitted to the first working fluid 102 via the second working fluid 103. Therefore, a time lag arises before the first working fluid 102 is moved by means of the driving force of the pump chamber 104 or 105, thereby raising a problem of the device 100 exhibiting poor response.

Since a large amount of force (energy) is lost before the driving force of the pump chamber 104 or 105 is presented as movement of the first working fluid 102, the device 100 also involves a problem of high energy consumption.

If the wettability of the first working fluid 102 to the inner wall of the channel 101 is rendered better than that of the second working fluid 103 to the inner wall of the channel 101, the spaces SP shown in FIG. 15 will not be formed, whereby a force generated by the pump chamber 104 or 105 will be efficiently exerted on the first working fluid 102. However, in this case, since frictional resistance between the first working fluid 102 and the inner wall surface of the channel 101 increases, the pump chambers 104 and 105 must be designed so as to generate a greater force, and thus the device 100 involves a problem of, for example, increased size and energy consumption.

SUMMARY OF THE INVENTION

The present invention has been conceived in order to solve the above-mentioned problems, and an object of the present invention is to provide a working-fluid moving device which utilizes a repulsive force induced by wettability between a working fluid (fluid to be moved) and the wall surface of a channel, for moving the working fluid through direct exertion of a driving force on the working fluid, thereby exhibiting reduced energy conversion loss and good response.

To achieve the above object, a working-fluid moving device of the present invention comprises a first working fluid, a second working fluid, and a housing body including a channel and housing the first working fluid and the second working fluid in the channel. The housing body includes a

deformable portion in which at least a portion of a wall of the channel is deformable so as to cause a change in a sectional shape of the channel. The housing body houses the first working fluid and the second working fluid such that, when the deformable portion is in a first state, the first working fluid is substantially in contact with a portion of an inner wall surface of the channel, the portion corresponding to the deformable portion, and the second working fluid is substantially in contact with the remaining portion of the inner wall surface of the channel. The first working fluid and the second working fluid are selected such that the first working fluid is inferior to the second working fluid in wettability to the inner wall surface of the channel. When the deformable portion in the first state is deformed to assume a second state different from the first state, the first working fluid is moved by means of a repulsive force induced by the inferior wettability of the first working fluid to the inner wall surface of the channel.

According to the above-described configuration, when the deformable portion of the channel is in the first state; for example, in the initial state, the first working fluid is substantially in contact with a portion of the inner wall surface of the channel corresponding to the deformable portion, and the second working fluid is substantially in contact with the remaining portion of the inner wall surface of the channel. The first working fluid is inferior to the second working fluid in wettability to the inner wall surface of the channel. Accordingly, when the deformable portion in the first state is deformed to assume the second state different from the first state, the first working fluid receives a repulsive force from the inner wall surface on the basis of the wettability of the first working fluid to the inner wall surface of the channel, and is thus moved within the channel.

Another working-fluid moving device of the present invention comprises a first working fluid, a second working fluid, and a housing body including at least a pair of opposed walls and housing the first working fluid and the second working fluid in a channel formed by the paired, opposed walls. The housing body includes a deformable portion in which at least a portion of the paired walls of the channel is deformable so as to cause a distance between the paired walls to change between a first distance and a second distance shorter than the first distance. The housing body houses the first working fluid and the second working fluid such that, when the distance between the paired walls at the deformable portion assumes the first distance, the first working fluid is substantially in contact with portions of inner surfaces of the paired walls, the portions corresponding to the deformable portion, and the second working fluid is substantially in contact with the remaining portions of the inner surfaces of the paired walls. The first working fluid and the second working fluid are selected such that the first working fluid is inferior to the second working fluid in wettability to the inner surfaces of the paired walls of the channel. When the deformable portion is deformed such that the distance between the paired walls changes from the first distance to the second distance, the first working fluid is moved by means of a repulsive force induced by the inferior wettability of the first working fluid to the inner surfaces of the paired walls.

According to the above-described configuration, when the distance between the paired walls at the deformable portion of the channel assumes the first distance, the first working fluid is substantially in contact with portions of the inner surfaces of the paired walls, which portions correspond to the deformable portion, and the second working fluid is substantially in

contact with the remaining portions of the inner surfaces of the paired walls. The first working fluid is inferior to the second working fluid in wettability to the inner surfaces of the paired walls of the channel. Accordingly, when the deformable portion is deformed such that the distance between the paired walls changes from the first distance to the second distance, the first working fluid receives a repulsive force from the inner surfaces of the paired walls on the basis of the wettability of the first working fluid to the inner surfaces of the paired walls, and is thus moved within the channel.

In either one of the above-described working-fluid moving devices, since the first working fluid is moved through utilization of a repulsive force stemming from inferior wettability between the wall surface of the channel and the first working fluid, deformation of the deformable portion is immediately converted to movement of the first working fluid. Thus, when an actuator is used to deform the deformable portion, the first working fluid can be moved while energy consumption of the actuator is suppressed. Since deformation of the deformable portion is converted to movement of the first working fluid without delay irrespective of whether an actuator is employed or not, a working-fluid moving device of excellent response is provided.

Preferably, in either one of the above-described working-fluid moving devices, the housing body is configured such that a plurality of deformable portions are formed on a single channel and such that, when each of the deformable portions is deformed, the first working fluid which is substantially in contact with the inner wall surface of the channel at the deformable portion is moved by means of the repulsive force.

The above-described configuration can achieve a function

substantially similar to that achievable by use of a plurality of working-fluid moving devices which are each configured such that a single deformable portion is formed on a single channel. Since the number of channels is reduced, the above-described configuration can reduce trouble, labor, and the like required for filling channels with the first and second working fluids. Also, the number of repetitions of adjusting pressure in the channel can be reduced, the pressure being a factor of determining the moving speed of the first working fluid.

In addition, since two or more deformable portions are used, even when at least one deformable portion is held undeformed while all of the other deformable portions are deformed, a change in pressure (a decrease in pressure and/or an increase in pressure) in the channel can be reduced (or smaller) in magnitude as compared with that which arises, as a result of deformation of the deformable portion, in a working-fluid moving device configured such that a single deformable portion is formed on a single channel.

Preferably, in any one of the above-described working-fluid moving devices, the first working fluid is an incompressible fluid, and the second working fluid is a compressible fluid. Also, preferably, the first working fluid is liquid, and the second working fluid is vapor of the first working fluid. Through such selection of the working fluids, a change in volume of the channel associated with deformation of the deformable portion can be absorbed by means of compression of the second working fluid.

Preferably, the first working fluid is a liquid metal such as mercury or a gallium alloy. Through use of such a liquid metal as the first working fluid, for example, the electrical connection state between switch terminals can be

changed over from an electrically connected state to an electrically disconnected state, and vice versa, by means of the first working fluid.

Preferably, any one of the above-described working-fluid moving devices further comprises an actuator for generating a force which causes deformation of at least a portion of a wall of the deformable portion, and at least the portion of the wall to be deformed is a diaphragm. Also, preferably, deformable walls of the deformable portion comprise a pair of opposed diaphragms, and a pair of actuators are fixedly attached to the corresponding diaphragms. Through employment of these configurations, the working-fluid moving device can be used as an active element such as a changeover switch, a rodless cylinder, or an optical display element. Employment of a pair of actuators as in the latter case allows easy increase in the magnitude of deformation of the deformable portion.

Preferably, the actuator comprises a film-type piezoelectric element including a piezoelectric/electrostrictive film or an antiferroelectric film. Also, preferably, the diaphragm, the deformable portion, or the inner wall surface of the deformable portion is formed from ceramic. Through employment of each of these features, a small-sized working-fluid moving device of excellent durability can be provided for use as an active element.

Preferably, the inner wall surface of the deformable portion is coated with a material whose wettability to the first working fluid is low, or the inner wall surface of the deformable portion is modified so as to assume inferior wettability to the first working fluid. Employment of either of these features enables easy provision of a working-fluid moving device in which a repulsive force is generated on the basis of wettability mentioned above, and expands the range of selection of the first working fluid and material for the housing

body.

Preferably, the channel of the housing body is formed as a closed space, and the housing body comprises a volume change absorptive portion for absorbing a change in volume of the closed space associated with deformation of the deformable portion. Employment of the volume change absorptive portion enables easy absorption of a change in volume of the deformable portion without need for compressibility of the second working fluid, thereby expanding the range of selection of the second working fluid.

Any one of the above-described working-fluid moving devices can be configured such that deformation of the deformable portion causes the first working fluid in a single mass to break into two or more fluid masses.

Preferably, in any one of the above-described working-fluid moving devices, the first working fluid is an electrically conductive fluid; the second working fluid is an electrically insulative fluid; and at least a pair of terminals are formed such that, before the deformable portion is deformed, the terminals assume one of an electrically connected state, in which the terminals are electrically connected via the first working fluid, and an electrically disconnected state, and such that, after the deformable portion is deformed to cause movement of the first working fluid, the terminals assume the other of the electrically disconnected state and the electrically connected state. Through employment of this feature, a changeover switch of excellent response can be provided.

Preferably, the working-fluid moving device comprising the above-mentioned paired terminals is configured such that a plurality of terminal connection-state changeover elements are formed on a single channel, each terminal connection-state changeover element comprising the

deformable portion and the paired terminals. This working-fluid moving device serves as a switching unit in which a plurality of switches are formed by use of a single channel.

The above-described configuration can achieve a switching function similar to that achievable by use of a plurality of working-fluid moving devices which are each configured such that a single terminal connection-state changeover element is formed on a single channel. Since the number of channels is reduced, the above-described configuration can reduce trouble, labor, and the like required for filling channels with the first and second working fluids. Also, a single terminal (electrode portion) can be used as a common electrode for two adjacent terminals located on opposite sides of the terminal. In this case, since the number of terminals can be reduced, the cost of the device can be reduced.

Furthermore, in this case, since two or more deformable portions are used, even when at least one deformable portion is held undeformed while all of the other deformable portions are deformed, a change in pressure (a decrease in pressure and/or an increase in pressure) in the channel can be reduced in magnitude as compared with that which arises, as a result of deformation of the deformable portion, in a working-fluid moving device configured such that a single terminal connection-state changeover element is formed on a single channel.

BRIEF DESCRIPTION OF THE DRAWINGS

Various other objects, features and many of the attendant advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed

description of the preferred embodiments when considered in connection with the accompanying drawings, in which:

FIG. 1A is a sectional view of a working-fluid moving device in an initial state according to a first embodiment of the present invention;

FIG. 1B is a plan view of the working-fluid moving device in the initial state according to the first embodiment;

FIG. 2A is a sectional view of the working-fluid moving device in a driven state according to the first embodiment;

FIG. 2B is a plan view of the working-fluid moving device in the driven state according to the first embodiment;

FIG. 3A is a sectional view of a working-fluid moving device in an initial state according to a second embodiment of the present invention;

FIG. 3B is a sectional view of the working-fluid moving device in a driven state according to the second embodiment;

FIG. 4A is a sectional view of a working-fluid moving device in an initial state according to a third embodiment of the present invention;

FIG. 4B is a sectional view of the working-fluid moving device in a driven state according to the third embodiment;

FIG. 5A is a plan view of a working-fluid moving device according to a fourth embodiment of the present invention;

FIG. 5B is a sectional view of the working-fluid moving device of FIG. 5A in an initial state cut by a plane along line 4-4 of FIG. 5A;

FIG. 5C is a sectional view of the working-fluid moving device of FIG. 5A in a driven state cut by a plane along line 4-4 of FIG. 5A;

FIG. 5D is a sectional view of the working-fluid moving device of FIG. 5A in an initial state cut by a plane along line 4a-4a of FIG. 5A;

FIG. 5E is a sectional view of the working-fluid moving device of FIG. 5A in a driven state cut by a plane along line 4a-4a of FIG. 5A;

FIG. 6A is a sectional view conceptually showing a modified embodiment of the working-fluid moving device in an initial state according the present invention;

FIG. 6B is a sectional view conceptually showing the modified embodiment of the working-fluid moving device in a driven state;

FIG. 7A is a plan view of a modified embodiment of the working-fluid moving device according to the present invention;

FIG. 7B is a sectional view of the working-fluid moving device of FIG. 7A in an initial state cut by a plane along line 5-5 of FIG. 7A;

FIG. 7C is a sectional view of the working-fluid moving device of FIG. 7A in a driven state cut by a plane along line 5-5 of FIG. 7A;

FIG. 7D is a view showing the function of the working-fluid moving device of FIG. 7A;

FIG. 8A is a sectional view conceptually showing another modified embodiment of the working-fluid moving device in an initial state according to the present invention;

FIG. 8B is a sectional view conceptually showing the working-fluid moving device of FIG. 8A in a driven state;

FIG. 8C is a view showing the function of the working-fluid moving device of FIG. 8A;

FIG. 9A is a sectional view conceptually showing still another modified embodiment of the working-fluid moving device in an initial state according to the present invention;

FIG. 9B is a sectional view conceptually showing the working-fluid

moving device of FIG. 9A in a driven state;

FIG. 9C is a view showing the function of the working-fluid moving device of FIG. 9A;

FIG. 10 is a conceptual plan view of the working-fluid moving device shown in FIGS. 9A and 9B;

FIG. 11A is a conceptual plan view of a further modified embodiment of the working-fluid moving device according to the present invention;

FIG. 11B is a view showing the function of the working-fluid moving device of FIG. 11A;

FIG. 12A is a conceptual plan view of a still further modified embodiment of the working-fluid moving device according to the present invention;

FIG. 12B is a view showing the function of the working-fluid moving device of FIG. 12A;

FIG. 13 is a conceptual view showing a still further modified embodiment of the working-fluid moving device according to the present invention;

FIG. 14 is a conceptual view of a conventional working-fluid moving device; and

FIG. 15 is a sectional view of the channel of the working-fluid moving device of FIG. 14.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the working-fluid moving device according to the present invention will next be described in detail with reference to the drawings. The present invention is not limited to the embodiments, but

may be changed, modified, or improved in various ways based on the knowledge of those skilled in the art without departing from the scope of the invention. In the following description, common structural portions among working-fluid moving devices are denoted by common reference numerals.

First Embodiment:

FIG. 1A is a longitudinal sectional view of a working-fluid moving device 10 in an initial state (first state) according to a first embodiment of the present invention, and FIG. 1B is a plan view of the working-fluid moving device 10 in the initial state. It is noted that FIG. 1A is a sectional view of the device 10 cut by a plane along line 2-2 of FIG. 1B. FIG. 2A is a longitudinal sectional view of the working-fluid moving device 10 in a driven state (at the time of voltage being applied, second state), and FIG. 2B is a plan view of the working-fluid moving device 10 in the driven state. It is noted that FIG. 2A is a sectional view of the device 10 cut by a plane along line 3-3 of FIG. 2B.

The working-fluid moving device 10 functions as an on-off switch and includes a housing body 11 of ceramic which substantially assumes the shape of a rectangular parallelepiped and has sides extending along the directions of mutually orthogonal X-axis, Y-axis, and Z-axis; and a piezoelectric/electrostrictive film 12 serving as an actuator. The housing body 11 has a channel 13 formed therein. The side of the housing body 11 extending along the Y-axis is the longest, and the sides extending along the X- and Z-axis are shorter than the side extending along the Y-axis.

The housing body 11 includes ceramic thin-plate bodies (hereinafter called "ceramic sheets") 11a-11c, which are sequentially arranged in layers in the positive direction of the Z-axis and integrated into a single unit

through firing. The ceramic sheet 11a has high rigidity and has a pair of electrodes 11d extending therethrough in the direction of the Z-axis. The paired electrodes 11d correspond to contacts of a switch and each include an electrode portion (terminal) 11d1 formed on the upper surface (a surface facing toward the positive direction of the Z-axis) of the ceramic sheet 11a and a connection portion 11d2 formed on the lower surface of the ceramic sheet 11a.

The ceramic sheet 11b includes a through-hole portion in a rectangular shape whose major and minor axes extend in the directions of the Y-axis and X-axis, respectively. The ceramic sheet 11c is thinner (shorter in length along the direction of the Z-axis) and lower in rigidity than the ceramic sheets 11a and 11b and thus forms a deformable diaphragm (ceramic diaphragm). The through-hole portion of the ceramic sheet 11b is closed by means of the upper surface of the ceramic sheet 11a and the lower surface of the ceramic sheet 11c, thereby constituting a channel 13. In other words, the channel 13 is defined by the side wall surface of the through-hole portion of the ceramic sheet 11b, the upper surface of the ceramic sheet 11a, and the lower surface of the ceramic sheet 11c and is a hollow space whose major axis extends along the Y-axis and whose section cut by a plane perpendicular to the major axis assumes a rectangular shape whose sides extend along the X- and Z-axis. Since the ceramic sheet 11c is deformable, the housing body 11 includes the channel 13 having a deformable portion.

The piezoelectric/electrostrictive film 12 is integrally formed on the upper surface of the ceramic sheet 11c through firing and generates a force (driving force) for deforming a central portion of the ceramic sheet 11c with

respect to the Y-axis direction (hereinafter such a central portion will be referred to as a Y-axis-direction central portion) when voltage is applied between an upper electrode and a lower electrode formed on the upper and lower surfaces, respectively, of the piezoelectric/electrostrictive film 12.

The channel 13 houses a first working fluid 14 and a second working fluid 15. The first working fluid 14 is inferior to (poor as compared with) the second working fluid 15 in wettability to the inner wall surface of the channel 13; specifically, to a pair of opposed inner wall surfaces of the channel 13 (in this case, the upper surface of the ceramic sheet 11a and the lower surface of the ceramic sheet 11c) and to the side wall surface of the through-hole of the ceramic sheet 11b. In other words, the first working fluid 14 is greater than the second working fluid 15 in contact angle with respect to the inner wall surface of the channel 13. The first working fluid 14 is electrically conductive and incompressible. By contrast, the second working fluid 15 is electrically insulative and compressible. In the present embodiment, the first working fluid 14 is liquid mercury, which is a liquid metal, whereas the second working fluid 15 is mercury vapor.

Next, the operation of the thus-configured working-fluid moving device 10 will be described. When no drive voltage is applied to the upper and lower electrodes of the piezoelectric/electrostrictive film 12, the working-fluid moving device 10 holds the initial state (herein, this state is also called "first state") shown in FIGS. 1A and 1B. In this case, the first working fluid 14 assumes the form of a single fluid mass (liquid mass) in an attempt to minimize its surface area and is substantially in contact with the inner wall surface of the channel 13 at its near Y-axis-direction central portion. The second working fluid 15 is substantially in contact with the

inner wall surface of the channel 13 at the remaining portion of the channel 13 where the first working fluid 14 is absent. As a result, the pair of electrode portions 11d1 are simultaneously covered with the electrically conductive first working fluid 14 and are thus brought into an electrically connected state. For the sake of convenience, the distance between the upper surface of the ceramic sheet 11a and the lower surface of the ceramic sheet 11c as measured at the Y-axis-direction central portion of the housing body 11 is called a "first distance."

In this state, when voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 12, the piezoelectric/electrostrictive film 12 attempts to contract in the lateral direction (i.e., in a plane substantially in parallel with the X-Y plane). Thus, as shown in FIG. 2A, a Y-axis-direction central portion (a portion to which the piezoelectric/electrostrictive film 12 is fixedly attached) of the ceramic sheet 11c is deformed downward in a bended condition. As a result, the sectional shape of the channel 13 at its near Y-axis-direction central portion changes such that the cross-sectional area of the channel 13 at its Y-axis-direction central portion (the area of the section of the channel 13 cut by a plane perpendicular to the direction of the Y-axis) is reduced. In this case, for the sake of convenience, the distance between the upper surface of the ceramic sheet 11a and the lower surface of the ceramic sheet 11c as measured at a Y-axis-direction central portion of the housing body 11 is called a "second distance." Also, the state in which the sectional shape of the channel 13 is thus changed is herein called a "second state."

At this time, since the first working fluid 14 is inferior to the second working fluid 15 in wettability to the wall surface of the channel 13, the first

working fluid 14 receives a repulsive force from the wall surface. As a result, in order to minimize the surface area, the first working fluid 14 moves in a split (separate) condition to opposite end portions of the channel 13 with respect to the Y-axis direction (hereinafter such opposite end portions will be referred to as Y-axis-direction opposite end portions), which opposite end portions have a large cross-sectional area. Thus, the first working fluid 14 assumes the form of a single fluid mass at each of the opposite end portions of the channel 13. On this occasion, the second working fluid 15 is compressed at the Y-axis-direction opposite end portions of the channel 13; and the second working fluid 15 flows into the Y-axis-direction central portion of the channel 13 via spaces (similar to the spaces SP in FIG. 15) formed between the first working fluid 14 and the inner wall surface (particularly corner portions of the inner wall surface) of the channel 13 and is also compressed at the central portion, thereby absorbing a change in volume of the channel 13. As a result, the paired electrode portions 11d1 are not covered with the first working fluid 14, but are covered with the electrically insulative second working fluid 15 to thereby assume an electrically disconnected state.

Subsequently, when application of voltage to the upper and lower electrodes of the piezoelectric/electrostrictive film 12 is stopped, the ceramic sheet 11c and the piezoelectric/electrostrictive film 12 are restored to their original state, and thus the working-fluid moving device 10 returns to the initial state shown in FIGS. 1A and 1B. Accordingly, the first working fluid 14 moves toward the Y-axis-direction central portion of the channel 13 and assumes the form of a single fluid mass at the portion. As a result, the paired electrode portions 11d1 are again covered with the electrically

conductive first working fluid 14 and assume an electrically connected state. Thus is completed description of operation of the present embodiment.

The working-fluid moving device 10 according to the first embodiment can yield the following effects.

(1) Since a force generated by the piezoelectric/electrostrictive film 12 is exerted directly on the first working fluid 14 via the ceramic sheet 11c and causes the first working fluid 14 to move, electric energy applied to the piezoelectric/electrostrictive film 12 is effectively used for moving the first working fluid 14. In other words, since energy conversion loss in relation to movement of the first working fluid 14 is small, a working-fluid moving device of low power consumption is provided.

(2) Since deformation of the ceramic sheet 11c (deformation of the wall of the channel 13) is exerted directly on the first working fluid 14 and causes the first working fluid 14 to move, a time lag between deformation of the ceramic sheet 11c (generation of a force by the piezoelectric/electrostrictive film 12) and movement of the first working fluid 14 is very short, thereby providing a working-fluid moving device (switch) of excellent response.

(3) Since a repulsive force to move the first working fluid 14 is generated simultaneously with deformation of the ceramic sheet 11c; i.e., without delay after deformation of the ceramic sheet 11c, a force generated by the piezoelectric/electrostrictive film 12 is transmitted immediately and without any waste to the first working fluid 14 and causes the first working fluid 14 to move.

(4) The working-fluid moving device 10 utilizes the surface tension of the first working fluid 14; i.e., the property of the first working fluid 14 of

minimizing its surface area. Thus, when the channel 13 is restored to its original shape after deformation of the channel 13 disappears, the first working fluid 14 which has once been split reliably returns to a single fluid mass. This restoration merely involves stopping of application of voltage to the piezoelectric/electrostrictive film 12 in contrast to the conventional technique in which energy is consumed for restoration to the initial state, thereby providing a working-fluid moving device of low power consumption. Notably, the device 10 can be returned more quickly from the driven state to its initial state through application to the piezoelectric/electrostrictive film 12 of a voltage whose polarity is opposite to that of the voltage having been applied to the piezoelectric/electrostrictive film 12.

(5) As described above, the working-fluid moving device 10 utilizes a repulsive force which the wall surface of the channel 13 exerts on the first working fluid 14, for causing the first working fluid 14 to split. In addition, the first working fluid 14 in a split condition is returned to a single fluid mass by means of surface tension, and therefore, it is possible that stable operation is obtained.

Second Embodiment:

Next, a working-fluid moving device 20 according to a second embodiment of the present invention will be described with reference to FIGS. 3A and 3B. FIG. 3A is a longitudinal sectional view of the working-fluid moving device 20 in an initial state (first state), and FIG. 3B is a longitudinal sectional view of the working-fluid moving device 20 in a driven state (at the time of voltage being applied, second state). A plan view of the working-fluid moving device 20 in the initial state is similar to FIG. 1B, and that in the driven state is similar to FIG. 2B. Thus, the plan views

are omitted. Also, illustration of the paired electrodes 11d is omitted.

The working-fluid moving device 20 merely differs from the above-described working-fluid moving device 10 in that the ceramic sheet 11a of the device 10 which forms a portion (lower wall) of the channel 13 is replaced with a deformable member similar to the ceramic sheet 11c of the device 10 on which the piezoelectric/electrostrictive film 12 is formed.

Specifically, the working-fluid moving device 20 includes a housing body 21 which in turn includes a pair of ceramic sheets 11c on each of which the piezoelectric/electrostrictive film 12 is integrally formed through firing, and the ceramic sheet 11b integrally sandwiched between the paired ceramic sheets 11c. A channel 22 is defined by the side wall surface of a through hole of the ceramic sheet 11b and the wall surface of each of the paired ceramic sheets 11c on which the piezoelectric/electrostrictive film 12 is not formed. The channel 22 houses the above-described first working fluid 14 and the above-described second working fluid 15.

The thus-configured working-fluid moving device 20 operates in a manner similar to that of the working-fluid moving device 10. Specifically, when no drive voltage is applied to the upper and lower electrodes of the paired piezoelectric/electrostrictive films 12, the working-fluid moving device 20 holds the initial state shown in FIG. 3A, and the first working fluid 14 assumes the form of a single fluid mass at a Y-axis-direction central portion of the channel 22 in an attempt to minimize its surface area. At this time, the first working fluid 14 is substantially in contact with the inner wall surface of the channel 22 at the Y-axis-direction central portion of the channel 22. The second working fluid 15 is substantially in contact with the remaining portion of the inner wall surface of the channel 22 where the first working

fluid 14 is absent. In this case, for the sake of convenience, the distance between the inner wall surfaces of the paired ceramic sheets 11c as measured at a Y-axis-direction central portion of the housing body 21 is called a "first distance."

In this state, when voltage is applied between the upper and lower electrodes of each of the paired piezoelectric/electrostrictive films 12, the piezoelectric/electrostrictive films 12 attempt to contract in the lateral direction (i.e., in corresponding planes substantially in parallel with the X-Y plane). Thus, as shown in FIG. 3B, central portions (portions to which the corresponding piezoelectric/electrostrictive films 12 are fixedly attached) of the paired ceramic sheets 11c are deformed in such a bended condition as to approach each other. As a result, the sectional shape of the channel 22 changes such that the cross-sectional area of the channel 22 at its Y-axis-direction central portion is reduced. In this case, for the sake of convenience, the distance between the inner wall surfaces of the paired ceramic sheets 11c is called a "second distance".

At this time, since the first working fluid 14 is inferior to the second working fluid 15 in wettability to the wall surface of the channel 22, the first working fluid 14 receives a repulsive force from the wall surface. As a result, in order to minimize the surface area, the first working fluid 14 moves in a split condition to Y-axis-direction opposite end portions of the channel 22, which portions have a large cross-sectional area. Thus, the first working fluid 14 assumes the form of a single fluid mass at each of the opposite end portions of the channel 22. On this occasion, the second working fluid 15 is compressed at the Y-axis-direction opposite end portions of the channel 22; and the second working fluid 15 flows into a substantially

central portion of the channel 22 via spaces formed between the first working fluid 14 and the inner wall surface (particularly corner portions of the inner wall surface) of the channel 22 and is also compressed at the central portion, thereby absorbing a change in volume of the channel 22.

Subsequently, when application of voltage to the upper and lower electrodes of the paired piezoelectric/electrostrictive films 12 is stopped, the ceramic sheets 11c and the piezoelectric/electrostrictive films 12 are restored to their original state, and thus the working-fluid moving device 20 returns to the initial state shown in FIG. 3A. Accordingly, the first working fluid 14 moves to the Y-axis-direction central portion of the channel 22 and assumes the form of a single fluid mass at the portion. Thus is completed description of operation of the present embodiment.

The working-fluid moving device 20 according to the second embodiment similarly yields the effects (1) to (5), which the above-described working-fluid moving device 10 yields. In addition, through use of the paired ceramic sheets 11c each provided with the piezoelectric/electrostrictive film 12, the magnitude of deformation of the channel 22 can be increased (the difference between the first distance and the second distance can be increased), and therefore, the device 20 yields the effect of reliably splitting the first working fluid 14.

Third Embodiment:

Next, a working-fluid moving device 30 according to a third embodiment of the present invention will be described with reference to FIGS. 4A and 4B. FIG. 4A is a longitudinal sectional view of the working-fluid moving device 30 in an initial state (first state), and FIG. 4B is a longitudinal sectional view of the working-fluid moving device 30 in a

driven state (at the time of voltage being applied, second state). A plan view of the working-fluid moving device 30 in the initial state is similar to FIG. 1B, and that in the driven state is similar to FIG. 2B except that the first working fluid 14 is split into three. Thus, the plan views are omitted. Also, illustration of the paired electrodes 11d is omitted.

The working-fluid moving device 30 structurally differs from the above-described working-fluid moving device 10 in that the channel 13 has a recess (a recess portion or cut portion) formed on its lower wall surface at a Y-axis-direction central portion thereof. Specifically, the working-fluid moving device 30 merely differs from the device 10 in that a housing body 31 is configured such that the ceramic sheet 11a of the working-fluid moving device 10 is replaced with a ceramic sheet 31a having a recess 31a1 formed thereon at a Y-axis-direction central portion thereof and that the housing body 31 includes a channel 32.

When no drive voltage is applied to the upper and lower electrodes of the piezoelectric/electrostrictive film 12, the thus-configured working-fluid moving device 30 holds the initial state shown in FIG. 4A, and the first working fluid 14 assumes the form of a single fluid mass at a Y-axis-direction central portion of the channel 32 in an attempt to minimize its surface area. The fluid mass is present throughout the recess portion 31a1. In this case, for the sake of convenience, the distance between the upper surface of the recess portion 31a1 of the ceramic sheet 31a and the lower surface of the ceramic sheet 11c is called a "first distance."

In this state, when voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 12, the piezoelectric/electrostrictive film 12 attempts to contract in the lateral

direction. Thus, as shown in FIG. 4B, a Y-axis-direction central portion of the ceramic sheet 11c is deformed downward in a bended condition. As a result, the cross-sectional area of the channel 32 at its Y-axis-direction central portion is reduced. In this case, for the sake of convenience, the distance between the upper surface of the recess portion 31a1 and the lower surface of the ceramic sheet 11c as measured at a Y-axis-direction central portion of the housing body 31 is called a "second distance."

At this time, since the first working fluid 14 is inferior to the second working fluid 15 in wettability to the wall surface of the channel 32, the first working fluid 14 receives a repulsive force from the wall surface. As a result, in order to minimize the surface area, a portion of the first working fluid 14 moves in a split condition to Y-axis-direction opposite end portions of the channel 32, which portions have a large cross-sectional area. Thus, the first working fluid 14 assumes the form of a single fluid mass at each of the opposite end portions of the channel 32 and at a central portion of the channel 32. In other words, the first working fluid 14 is split into three fluid masses. On this occasion, the second working fluid 15 is compressed at the Y-axis-direction opposite end portions of the channel 32; and the second working fluid 15 flows toward a central portion of the channel 32 via spaces formed between the first working fluid 14 and the inner wall surface (particularly corner portions of the inner wall surface) of the channel 32 and is also compressed between the central fluid mass of the first working fluid 14 and the opposite-end fluid masses of the first working fluid 14, thereby absorbing a change in volume of the channel 32.

Subsequently, when application of voltage to the upper and lower electrodes of the piezoelectric/electrostrictive film 12 is stopped, the ceramic

sheet 11c and the piezoelectric/electrostrictive film 12 are restored to their original state, and thus the working-fluid moving device 30 returns to the initial state shown in FIG. 4A. Accordingly, the fluid masses of the first working fluid 14 present at the opposite end portions of the channel 32 move toward the Y-axis-direction central portion of the channel 32 and assumes the form of a single fluid mass at the portion. Thus is completed description of operation of the present embodiment.

The working-fluid moving device 30 according to the third embodiment similarly yields the effects (1) to (5), which the above-described working-fluid moving device 10 yields. In addition, since the recess portion 31a1 is formed, the first working fluid 14 is reliably present ,in the initial state, at a substantially central portion of the channel 32 in the form of a single fluid mass, thereby yielding the effect of imparting higher stability to movement of the first working fluid 14.

Fourth Embodiment:

Next, a working-fluid moving device 40 according to a fourth embodiment of the present invention will be described with reference to FIGS. 5A to 5E. FIG. 5A is a plan view of the working-fluid moving device 40. FIGS. 5B and 5C are sectional views of the working-fluid moving device 40 in an initial state (first state) and a driven state (at the time of voltage being applied, second state), respectively, cut by a plane along line 4-4 shown in FIG. 5A. FIGS. 5D and 5E are sectional views of the working-fluid moving device 40 in an initial state (first state) and a driven state (at the time of voltage being applied, second state), respectively, cut by a plane along line 4a-4a shown in FIG. 5A.

The working-fluid moving device 40 includes a housing body 41 of

ceramic which substantially assumes the shape of a rectangular parallelepiped and has sides extending along the directions of mutually orthogonal X-axis, Y-axis, and Z-axis; and a piezoelectric/electrostrictive film 42 serving as an actuator. The housing body 41 has a channel 43 formed therein. As in the case of the above-described embodiments, the channel 43 houses liquid mercury as the first working fluid 14 and mercury vapor as the second working fluid 15. Dimensional relation among the sides of the housing body 41 is as follows: a side extending along the Y-axis is the longest; a side extending along the X-axis is the second longest; and a side extending along the Z-axis is the shortest.

The housing body 41 includes ceramic sheets 41a-41c, which are sequentially arranged in layers in the positive direction of the Z-axis and integrated into a single unit through firing. The ceramic sheet 41a has high rigidity. A pair of working-fluid-position-retaining thin-film portions 41a1 are formed on the upper surface of the ceramic sheet 41a at respective positions located a predetermined distance away from a Y-axis-direction central portion of the channel 43 (at respective positions located outside a thin-walled portion 41c1 as viewed in plane). The paired working-fluid-position-retaining thin-film portions 41a1 are formed from a material (e.g., platinum or gold) exhibiting good wettability to the first working fluid 14.

The ceramic sheet 41b, in fact, comprises a ceramic sheet 41b1 and a ceramic sheet 41b2 arranged in layer on the ceramic sheet 41b1. The ceramic sheet 41b includes a through-hole portion in a rectangular shape which is formed at a central portion thereof as viewed in plane and whose major and minor axes extend in the directions of the Y-axis and X-axis,

respectively. The ceramic sheet 41c includes the oval thin-walled portion 41c1 which is formed at a central portion thereof as viewed in plane, and a thick-walled portion 41c2 which is formed around the thin-walled portion 41c1. Since the thin-walled portion 41c1 is low in rigidity, the thin-walled portion 41c1 constitutes a deformable diaphragm (ceramic diaphragm).

As shown FIGS. 5D and 5E, the ceramic sheet 41b1 includes a through-hole portion in the rectangular shape only at the central portion in the directions of the X-axis. The ceramic sheet 41b2 includes a through-hole portion in the rectangular shape at the central portion in the directions of the X-axis. The through-hole portion in the rectangular shape formed in the ceramic sheet 41b1 corresponds to the through-hole portion in the rectangular shape formed in the ceramic sheet 41b2 as viewed in plane, and form the through-hole portion in the ceramic sheet 41b mentioned above. Further, the ceramic sheet 41b2 includes a through-hole portion in the oval shape corresponding to the oval thin-walled portion 41c1.

The through-hole portion of the ceramic sheet 41b forms a channel 43 together with the upper surface of the ceramic sheet 41a and the lower surface of the ceramic sheet 41c. The through-hole portion in the oval shape formed in the ceramic sheet 41b2 provide a clearance for the piezoelectric/electrostrictive film 42 and the thin-walled portion 41c1 to deform. Since this clearance is very thin, the first working fluid 14 can not enter the clearance. Since the thin-walled portion 41c1 of the ceramic sheet 41c is deformable, the channel 43 includes a deformable portion. A piezoelectric/electrostrictive film 42 assumes an oval shape which is slightly smaller than the thin-walled portion 41c1 of the ceramic sheet 41c as viewed in plane. The piezoelectric/electrostrictive film 42 is integrally

formed on the upper surface of the thin-walled portion 41c1 through firing. The piezoelectric/electrostrictive film 42 generates a force for deforming downward the thin-walled portion 41c1, which partially forms the upper surface of the channel 43, when voltage is applied between an upper electrode and a lower electrode formed on the upper and lower surfaces, respectively, of the piezoelectric/electrostrictive film 42.

The thus-configured working-fluid moving device 40 operates in a manner similar to that of the working-fluid moving device 10. Further, since the working-fluid moving device 40 has the paired working-fluid-position-retaining thin-film portions 41a1, in its initial state, the first working-fluid 14 is reliably present at a Y-axis-direction central portion of the channel 43 in the form of a single fluid mass. The piezoelectric/electrostrictive film 42 deforms downward in its driven state. At this time, the thin-walled portion 41c1 comes into contact with the upper surface of the ceramic sheet 41b1 at about central portion in the direction of the X axis. As a result, the first working-fluid 14 receives a repulsive force from the wall surface of the channel 43, since the cross-sectional area of the channel 43 is reduced. Therefore, the first working-fluid 14 splits into two fluid masses and each moves to assume the form of a single fluid mass at each of the end portions of the channel 43. Thus, the working-fluid moving device 40 yields the effect of imparting higher stability to movement of the first working fluid 14 as well as the effects (1) to (5), which the working-fluid moving device 10 yields.

As described above, the embodiments of the present invention provide a working-fluid moving device exhibiting excellent response and low energy consumption. Notably, the present invention is not limited to the

above-described embodiments, but may be modified in various forms as described below without departing from the scope of the invention.

Modified Embodiment 1:

The first working fluid 14 may be a liquid metal other than mercury, such as a gallium alloy, liquid such as water or oil, or gas such as an inert gas. The second working fluid 15 may be any fluid so long as it does not combine or react with the first working fluid 14 and does not easily dissolve in the first working fluid 14. Examples of such fluid include a magnetic material, a liquid metal such as a gallium alloy, water, oil, and an inert gas.

Even when an inert gas is used as the second working fluid 15, if fluid like a gallium alloy which easily reacts with oxygen or water to form an oxide film is to be used as the first working fluid 14, it is preferable that oxygen or water is completely removed from the above-mentioned channel before the first working fluid 14 is introduced into the channel. By doing so, the working fluids can maintain high movability (easiness of movement) over a long period of time. A liquid metal or the like can be easily injected into the channel by use of, for example, a dispenser.

A working fluid may be injected into the channel in the following manner. A channel pressure adjustment hole which establishes communication between the channel and the exterior of the housing body, and a working-fluid injection hole which establishes communication between the channel and the exterior of the housing body and has a predetermined diameter (or a predetermined sectional shape), are formed in the housing body. The working fluid is injected into the channel by means of the pressure difference between a pressure in the channel and a pressure to be applied to the working fluid so as to inject the working fluid through the

working-fluid injection hole. This method can accurately adjust the amount of the working fluid to be injected through adjustment of the pressure difference and/or the diameter (or the sectional shape) of the working-fluid injection hole.

Modified Embodiment 2:

The piezoelectric/electrostrictive films 12 and 42 of the above-described embodiments may assume the form of a laminated piezoelectric/electrostrictive element in which a plurality of piezoelectric/electrostrictive films sandwiched between electrodes are arranged in layers. The deformable portion (diaphragm) of the channel 13, 22, 32, or 43 may be pressed and deformed through deformation of a piezoelectric/electrostrictive film. In this case, the piezoelectric/electrostrictive film and the deformable portion do not need to be integrally formed through firing. In place of the piezoelectric/electrostrictive film 12 or 42, a film-type piezoelectric element formed of an antiferroelectric film may be used as an actuator for deforming the deformable portion. Furthermore, force which has been intensively studied in micromachine researches may be used. Specifically, in place of a deforming force generated by a piezoelectric film, an electrostatic force which is generated between electrodes which face each other with a gap formed therebetween, or a deforming force which is generated in a shape-memory alloy through electricity-effected heating may be used for deforming the deformable portion.

Modified Embodiment 3:

The inner wall surface of the channel 13, 22, 32, or 43 including the inner wall surface of the deformable portion may be coated with a material

which has an inferior wettability to the first working fluid 14. Alternatively, the inner wall surface of the channel 13, 22, 32, or 43 including the inner wall surface of the deformable portion may be modified so as to assume inferior wettability to the first working fluid 14. Also, a wettability modifier may be added to the first working fluid 14 in order to modify the first working fluid 14 such that the first working fluid 14 assumes inferior wettability to the inner wall surface of the channel 13, 22, 32, or 43 including the deformable portion. In this case, an appropriate alloy (a single alloy or a plurality of alloys having adjusted compositions) may be used as a wettability modifier for the first working fluid 14.

Modified Embodiment 4:

In the above-described embodiments, a single device is provided with a single deformable portion. However, a single device may be provided with a plurality of deformable portions. In this case, the deformable portions may be formed in a linear arrangement, in a matrix arrangement, or in a random arrangement.

Modified Embodiment 5:

In the above-described embodiments, the second working fluid 15 is compressible. However, the second working fluid 15 may be incompressible. In this case, preferably, in order to absorb a change in volume of the channel 13, 22, 32, or 43 caused by the piezoelectric/electrostrictive film 12 or 42, a deformable, volume change absorptive portion which may include a diaphragm or the like is provided at Y-axis-direction opposite end portions or a Y-axis-direction one end portion of the channel 13, 22, 32, or 43.

Modified Embodiment 6:

The device of each of the above-described embodiments is configured so as to serve as an on-off switch, but may be applied to a relay. Also, the device may be configured such that the piezoelectric/electrostrictive film 12 or 42 is removed, and the deformable portion is pressed by means of an object of detection. The thus-configured device can be used as a position detection sensor.

Modified Embodiment 7:

A working-fluid moving device according to the present invention may be used for implementing, for example, a so-called rodless cylinder in the form of a micromachine. As disclosed in, for example, US Patent No. 3,779,401, a rodless cylinder is configured such that an operating section is completely enclosed. The operating section (corresponding to the first working fluid 14 in the present application) which moves within an enclosed space is magnetically connected to a working section, whereby the working section performs a reciprocating motion at the exterior of the enclosed space. In this manner, movement of the operating section can be transmitted to the exterior of the rodless cylinder. Thus, a micro rodless cylinder can be obtained by use of a working-fluid moving device of the present invention in the following manner: a magnetic substance is used as the first working fluid 14 of the present invention, and a working section which is magnetically connected to the first working fluid 14 is formed at the exterior of the device.

Modified Embodiment 8:

Preferably, a working-fluid moving device is configured as schematically shown in FIGS. 6A and 6B, which are schematic sectional views showing the device in the initial state and in the driven state,

respectively. Specifically, the working-fluid moving device is configured such that when it is in the initial state (firs state), the sectional area of a portion of the channel located on the side toward the negative direction of the Y-axis becomes greater than that of a portion of the channel located on the side toward the positive direction of the Y-axis. In addition, the working-fluid moving device is configured such that when it is in the driven state (second state), the sectional area of the portion of the channel located on the side toward the negative direction of the Y-axis becomes smaller than that of the portion of the channel located on the side toward the positive direction of the Y-axis. Through employment of this configuration, in the first and second states, the first working fluid can be reliably held at respective target positions.

Modified Embodiment 9:

A working-fluid moving device according to the present invention can serve as an optical display element through employment of, for example, the following configuration: a translucent material is used partially or entirely for the wall of the channel 13, 22, 32, or 43; and a bubble, a mass of colored liquid or fluorescent liquid, or a light-reflective, very small metal element is used as the first working fluid 14. Furthermore, a working-fluid moving device according to the present invention can be used as a memory element through employment of the following system: the position of the first working fluid 14 is detected from the outside by use of, for example, magnetic, optical, or electrical means. Also, a gyro or a like sensor can be formed in the following manner: the first working fluid 14 is caused to perform a vibratory motion, and the influence of an external force such as the Coriolis force on the motion is sensed by use of, for example, electrical or optical

means.

Modified Embodiment 10:

In the above-described embodiments, a plurality of ceramic green sheets are integrated through firing, thereby forming the aforementioned housing body. Alternatively, the housing body may be formed in the following manner: ceramic or glass sheets or the like obtained through firing are processed by means of, for example, laser machining, sandblasting, etching, or photolithography; and the thus-processed sheets are bonded (joined) together. This bonding process may use a thermosetting resin, an ultraviolet (UV)-curing resin, or the like as a bonding agent. Such a bonding agent may be applied to a bond surface in the form of a uniform film by use of a spin coater or the like, whereby bonding of higher gastightness can be performed.

Modified Embodiment 11:

As schematically shown in FIG. 7D, Modified Embodiment 11 is a working-fluid moving device 50 configured as an SPST (Single-Pole Single-Throw) switch having one pole and one throw. FIG. 7A is a plan view of the working-fluid moving device 50. FIG. 7B is a sectional view of the working-fluid moving device 50 in an initial state (first state) cut by a plane along line 5-5 of FIG. 7A. FIG. 7C is a sectional view of the working-fluid moving device 50 in a driven state (at the time of voltage being applied, second state) cut by a plane along line 5-5 of FIG. 7A.

The working-fluid moving device 50 merely differs from the working-fluid moving device 40 shown in FIG. 5 in that a housing body 51 including a channel 52 is configured such that the ceramic sheet 41a of the device 40 is replaced with a ceramic sheet 51a.

The ceramic sheet 51a has high rigidity and has electrodes 53 and 54 extending therethrough in the direction of the Z-axis. The electrodes 53 and 54 are formed from an electrically conductive material (e.g., platinum or gold) of good wettability to the first working fluid 14 and have the function to retain the position of the first working fluid 14 as in the case of the aforementioned paired thin-film portions 41a1. The electrode 53 constitutes a pole of the SPST switch, and the electrode 54 constitutes a throw of the SPST switch.

The electrodes 53 and 54 include electrode portions (terminals) 53a and 54a, respectively, formed on the upper surface (a surface facing toward the positive direction of the Z-axis) of the ceramic sheet 51a. The electrode portions 53a and 54a are disposed at respective positions located a predetermined distance away from a Y-axis-direction central portion of the channel 52 (at respective positions located outside the thin-walled portion 41c1 as viewed in plane). The electrodes 53 and 54 also include connection portions 53b and 54b formed on the lower surface of the ceramic sheet 51a.

The thus-configured working-fluid moving device 50 operates in a manner substantially similar to that of the working-fluid moving device 10. Specifically, when no drive voltage is applied to the upper and lower electrodes of the piezoelectric/electrostrictive film 42, the working-fluid moving device 50 holds the initial state shown in FIG. 7B. In this case, the first working fluid 14 assumes the form of a single fluid mass at a central portion of the channel 52. As a result, the electrode portions 53a and 54a are simultaneously covered with the electrically conductive first working fluid 14 in the form of a single fluid mass, and electrodes 53 and 54 are thus in

an electrically connected state.

In this state, when voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 42, as shown in FIG. 7C, a Y-axis-direction central portion (the thin-walled portion 41c1) of the ceramic sheet 41c is deformed downward in a bended condition. As a result, the cross-sectional area of the channel 52 at its Y-axis-direction central portion (the area of the section of the channel 52 cut by a plane perpendicular to the direction of the Y-axis) is reduced.

Accordingly, the first working fluid 14 receives a repulsive force from the wall surface of the channel 52, and in order to minimize the surface area, the first working fluid 14 moves in a split (separate) condition to Y-axis-direction opposite end portions of the channel 52, which portions have a large cross-sectional area. Thus, the first working fluid 14 assumes the form of a single fluid mass at each of the opposite end portions of the channel 52. As a result, the electrode portions 53a and 54a are covered with the two corresponding separate fluid masses of the first working fluid 14. However, since the electrically insulative second working fluid 15 is present between the two separate fluid masses of the first working fluid 14, the electrodes 53 and 54 are in an electrically disconnected state.

Subsequently, when application of voltage to the upper and lower electrodes of the piezoelectric/electrostrictive film 42 is stopped, the ceramic sheet 41c and the piezoelectric/electrostrictive film 42 are restored to their original state, and thus the working-fluid moving device 50 returns to the initial state shown in FIGS. 7B. Accordingly, the two separate fluid masses of the first working fluid 14 (the fluid masses are also subjected to force exerted by the compressed second working fluid 15 at the Y-axis-direction

opposite end portions of the channel 52) move toward the Y-axis-direction central portion of the channel 52 and assumes the form of a single fluid mass at the portion. As a result, the electrodes 53 and 54 again assume an electrically connected state. Thus is completed description of operation of the present modified embodiment.

In the present modified embodiment, the deformable portion (the thin-walled portion 41c1 exposed to the channel 52 and the piezoelectric/electrostrictive film 42 (and additionally the first working fluid 14)) constitutes an connection-state changeover element (terminal connection-state changeover element) of an SPST switch. As in the case of the working-fluid moving device 40, since the working-fluid moving device 50 is configured such that the electrode portions 53a and 54a also function as thin-film portions for retaining the position of the first working fluid 14, in its initial state, the first working fluid 14 is reliably present at the Y-axis-direction central portion of the channel 52 in the form of a single fluid mass. As a result, the working-fluid moving device 50 yields the effect of imparting higher stability to movement of the first working fluid 14 as well as the effects (1) to (5), which the working-fluid moving device 10 yields; therefore, the working-fluid moving device 50 serves as an SPST switch which enables high-speed switching and exhibits stable changeover operation. Also, in the present modified embodiment, the electrode portions 53a and 54a are covered with the first working fluid 14 at all times, thereby providing an advantage of the electrode portions 53a and 54a being unlikely to deteriorate.

Modified Embodiment 12:

As schematically shown in FIG. 8C, Modified Embodiment 12 is a

working-fluid moving device 60 configured as an SPDT (Single-Pole Double-Throw) switch having one common terminal (COM), one normally closed (NC) terminal, and one normally open (NO) terminal. FIG. 8A is a longitudinal sectional view of the working-fluid moving device 60 in an initial state. FIG. 8B is a longitudinal sectional view of the working-fluid moving device 60 in an operating state (changeover state).

The working-fluid moving device 60 assumes a configuration substantially similar to that achievable by use of two working-fluid moving devices 50 shown in FIG. 7, the devices 50 being arranged adjacently to each other in the direction of the Y-axis and their housing bodies being integrated. Specifically, a housing body 61 of the working-fluid moving device 60 has two channels 62 and 63 which are arranged along the Y-axis. For the sake of convenience, a channel shown at the left side of FIGS. 8A and 8B is called a "left-hand channel (first channel)" 62, whereas a channel shown at the right side of FIGS. 8A and 8B is called a "right-hand channel (second channel)" 63. Each of the channels 62 and 63 houses the first working fluid 14 and the second working fluid 15.

A piezoelectric/electrostrictive film 64 is provided above a central portion of the left-hand channel 62 and is fixedly attached to the upper surface of a thin-walled portion 65 which constitutes a deformable portion of the left-hand channel 62. The piezoelectric/electrostrictive film 64 and the thin-walled portion 65 are configured in the same manner as are the piezoelectric/electrostrictive film 42 and thin-walled portion 41c1 of the working-fluid moving device 50. Similarly, a piezoelectric/electrostrictive film 66 is provided above a central portion of the right-hand channel 63 and is fixedly attached to the upper surface of a thin-walled portion 67 which

constitutes a deformable portion of the right-hand channel 63. The piezoelectric/electrostrictive film 66 and the thin-walled portion 67 are also configured in the same manner as are the piezoelectric/electrostrictive film 42 and thin-walled portion 41c1 of the working-fluid moving device 50.

The housing body 61 has a total of four electrodes 62a, 62b, 63a, and 63b. A pair of electrodes 62a and 62b include electrode portions 62a1 and 62b1, respectively, disposed on the lower surface of the left-hand channel 62. A pair of electrodes 62a and 62b include connection portions 62a2 and 62b2, respectively, formed on the lower surface of the housing body 61. The positional relation of the paired electrodes 62a and 62b to the channel 62 is similar to that of the paired electrodes 53 and 54 to the channel 52 in the working-fluid moving device 50.

A pair of electrodes 63a and 63b include electrode portions 63a1 and 63b1, respectively, disposed on the lower surface of the right-hand channel 63. A pair of electrodes 63a and 63b include connection portions 63a2 and 63b2, respectively, disposed on the lower surface of the housing body 61. The positional relation of the paired electrodes 63a and 63b to the channel 63 is similar to that of the paired electrodes 53 and 54 to the channel 52 in the working-fluid moving device 50.

The connection portion 62b2 of the electrode 62b located on the right side of the left-hand channel 62 is electrically connected, at the exterior of the housing body 61, to the connection portion 63a2 of the electrode 63a located on the left side of the right-hand channel 63. This connection point constitutes the common terminal COM of the SPDT switch.

Next, the operation of the working-fluid moving device 60 will be described. As shown in FIG. 8A, when the working-fluid moving device 60

is in the initial state, voltage is not applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 64 of the left-hand channel 62 (this state is called as a "first state"). Accordingly, the first working fluid 14 in the left-hand channel 62 assumes the form of a single fluid mass at a central portion of the left-hand channel 62. This single fluid mass simultaneously covers the electrode portions 62a1 and the 62b1. As a result, the electrodes 62a and 62b are in an electrically connected state.

When the working-fluid moving device 60 is in the initial state, voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 66 of the right-hand channel 63 (this state is called as a "second state"). Accordingly, the piezoelectric/electrostrictive film 66 is operated, thereby causing the thin-walled portion 67 to be deformed downward in a bending condition, and the cross-sectional area of the right-hand channel 63 at its Y-axis-direction central portion is reduced. As a result, the first working fluid 14 in the right-hand channel 63 receives a repulsive force from the wall surface of the right-hand channel 63, and splits into two fluid masses.

In this state, the left-hand fluid mass of the first working fluid 14 in the right-hand channel 63 covers the left-hand electrode portion 63a1. The right-hand fluid mass of the first working fluid 14 in the right-hand channel 63 covers the right-hand electrode portion 63b1. However, since the electrically insulative second working fluid 15 is present between the two separate fluid masses of the first working fluid 14, the electrodes 63a and 63b are in an electrically disconnected state.

Next, voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 64 of the left-hand channel 62 (this

state is called a "second state"), and application of voltage between the upper and lower electrodes of the piezoelectric/electrostrictive film 66 of the right-hand channel 63 is stopped (this state is called a "first state"). This state, for the sake of convenience, is called a "changeover state." In the changeover state, as shown in FIG. 8B, the piezoelectric/electrostrictive film 64 is operated, thereby causing the thin-walled portion 65 to be deformed downward in a bending condition, and the cross-sectional area of the left-hand channel 62 at its Y-axis-direction central portion is reduced. As a result, the first working fluid 14 in the left-hand channel 62 receives a repulsive force from the wall surface of the left-hand channel 62, and splits into two fluid masses.

In this state, the left-hand fluid mass of the first working fluid 14 covers the left-hand electrode portion 62a1 in the left-hand channel 62. The right-hand fluid mass of the first working fluid 14 covers the right-hand electrode portion 62b1 in the left-hand channel 62. However, since the electrically insulative second working fluid 15 is present between the two separate fluid masses of the first working fluid 14, the electrodes 62a and 62b are in an electrically disconnected state.

The piezoelectric/electrostrictive film 66 of the right-hand channel 63 is restored to its original state, and thus the thin-walled portion 67 returns to an ordinary state (a flat shape). As a result, the first working fluid 14 in the right-hand channel 63 assumes the form of a single fluid mass at a central portion of the right-hand channel 63. This single fluid mass simultaneously covers the electrode portions 63a1 and the 63b1. As a result, the electrodes 63a and 63b are in an electrically connected state.

Subsequently, application of voltage between the upper and lower

electrodes of the piezoelectric/electrostrictive film 64 of the left-hand channel 62 is stopped, and voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 66 of the right-hand channel 63. As a result, the working-fluid moving device 60 returns to the initial state shown in FIG. 8A. Thus is completed description of operation of the working-fluid moving device 60.

As described above, in the working-fluid moving device 60, the electrodes 62b and 63a are held in an electrically connected state, irrespective of whether the device 60 is in the initial state or in the changeover state. The electrodes 62a and 62b are in an electrically connected state when the working-fluid moving device 60 is in the initial state, and are in an electrically disconnected state when the device 60 is in the changeover state. Accordingly, the electrode 62a constitutes a normally closed terminal. The electrodes 63a and 63b are in an electrically disconnected state when the working-fluid moving device 60 is in the initial state, and are in an electrically connected state when the device 60 is in the changeover state. Accordingly, the electrode 63b constitutes a normally open terminal.

As is apparent from the above description, the working-fluid moving device 60 utilizes two working-fluid moving devices 50. Therefore, the working-fluid moving device 60 serves as an SPDT switch having all of the advantages, such as high-speed response, of the working-fluid moving device 50.

In the present modified embodiment, in the initial state, voltage must be applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 66. However, the following configuration

may be employed: the piezoelectric/electrostrictive film 66 and the thin-walled portion 67 are formed beforehand in such a manner as to be deformed downward in a bending condition as shown in FIG. 8A when voltage is not applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 66; and in the changeover state, voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 66, whereby the piezoelectric/electrostrictive film 66 and the thin-walled portion 67 are caused to be deformed upward so as to establish the state shown in FIG. 8B.

Modified Embodiment 13:

As schematically shown in FIG. 9C, Modified Embodiment 13 is a working-fluid moving device 70 configured as an SPDT switch as in the case of Modified Embodiment 12. FIG. 9A is a longitudinal sectional view of the working-fluid moving device 70 in an initial state. FIG. 9B is a longitudinal sectional view of the working-fluid moving device 70 in an operating state (changeover state). FIG. 10 is a schematic plan view of the working-fluid moving device 70.

The working-fluid moving device 70 is configured such that three electrode portions (terminals) are provided in a single channel, thereby constituting an SPDT switch. Specifically, a housing body 71 of the working-fluid moving device 70 includes a single channel 72 which linearly extends along the Y-axis. The channel 72 houses first working fluids 14a and 14b and the second working fluid 15. The first working fluid is present in the form of two fluid masses 14a and 14b in either of the initial state and the changeover state, which will be described later. In FIG. 9A and FIG.

9B, for the sake of convenience, the masses of the first working fluid located on the left and right sides of the channel 72 are called a "left-hand first working fluid 14a" and a "right-hand first working fluid 14b," respectively. The second working fluid 15 fills a portion of the channel 72 where the first working fluid 14 is absent.

The housing body 71 includes a piezoelectric/electrostrictive film 74 located above the channel 72 and at the left side of a central portion of the channel 72 as shown in FIG. 9A and FIG. 9B. The piezoelectric/electrostrictive film 74 is fixedly attached to the upper surface of a thin-walled portion 75 which is located at the left side of a central portion of the channel 72 and constitutes a deformable portion. The piezoelectric/electrostrictive film 74 and the thin-walled portion 75 are configured in the same manner as are the piezoelectric/electrostrictive film 42 and thin-walled portion 41c1 of the working-fluid moving device 40 or 50.

Similarly, the housing body 71 includes a piezoelectric/electrostrictive film 76 located above the channel 72 and at the right side of a central portion of the channel 72 in FIG. 9A and FIG. 9B. The piezoelectric/electrostrictive film 76 is fixedly attached to the upper surface of a thin-walled portion 77 which is located at the right side of a central portion of the channel 72 in FIG. 9A and FIG. 9B and constitutes a deformable portion. The piezoelectric/electrostrictive film 76 and the thin-walled portion 77 are configured in the same manner as are the piezoelectric/electrostrictive film 42 and thin-walled portion 41c1 of the working-fluid moving device 40 or 50.

The housing body 71 has a total of three electrodes 72a, 72b, and 72c, from left to right in FIG. 9A and FIG. 9B. The electrodes 72a, 72b,

72c include electrode portions 72a1, 72b1, and 72c1, respectively, disposed on the lower surface of the channel 72. The electrode portion 72a1 is formed slightly leftward with respect to a position located directly under the thin-walled portion 75; the electrode portion 72b1 is formed directly under a portion between the thin-walled portion 75 and the thin-walled portion 77; and the electrode portion 72c1 is formed slightly rightward with respect to a position located directly under the thin-walled portion 77. The electrodes 72a, 72b, and 72c include connection portions 72a2, 72b2, and 72c2, respectively, formed on the lower surface of the housing body 71.

Next, the operation of the working-fluid moving device 70 will be described. As shown in FIG. 9A, when the working-fluid moving device 70 is in the initial state, voltage is not applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 74. At this time, the left-hand first working fluid 14a assumes the form of a relatively long, single fluid mass and covers the electrode portions 72a1 and 72b1. As a result, the electrodes 72a and 72b are in an electrically connected state.

When the working-fluid moving device 70 is in the initial state, voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 76. Accordingly, the piezoelectric/electrostrictive film 76 is operated, thereby causing the thin-walled portion 77 to be deformed downward in a bending condition, and the cross-sectional area of the channel 72 under the thin-walled portion 77 is reduced. As a result, the right-hand first working fluid 14b receives a repulsive force from the wall surface of the channel 72 (the lower surface of the thin-walled portion 77), and assumes the form of a single fluid mass which is absent directly under the thin-walled portion 77 and is present at a

right-hand end portion of the channel 72 in FIG. 9A.

In this state, the right-hand first working fluid 14b covers the electrode portion 72c1, but does not cover the electrode portion 72b1. The electrically insulative second working fluid 15 is present between the left-hand first working fluid 14a and the right-hand working fluid 14b. As a result, the electrodes 72c and 72b are in an electrically disconnected state.

Next, voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 74, and application of voltage between the upper and lower electrodes of the piezoelectric/electrostrictive film 76 is stopped. This state, for the sake of convenience, is called a "changeover state." In the changeover state, as shown in FIG. 9B, the piezoelectric/electrostrictive film 74 is operated, thereby causing the thin-walled portion 75 to be deformed downward in a bending condition, and the cross-sectional area of the channel 72 under the thin-walled portion 75 is reduced. As a result, the left-hand first working fluid 14a receives a repulsive force from the wall surface of the channel 72 (the lower surface of the thin-walled portion 75), and splits into two fluid masses such that one fluid mass is a relatively short fluid mass present at a left-hand end portion of the channel 72 in FIG. 9B, while the other fluid mass moves rightward in FIG. 9B and is integrated with the right-hand first working fluid 14b.

In this state, the left-hand first working fluid 14a covers the electrode portions 72a1, but does not cover the electrode portion 72b1. The electrically insulative second working fluid 15 is present between the left-hand first working fluid 14a and the right-hand working fluid 14b. As a result, the electrodes 72a and 72b are in an electrically disconnected state.

The piezoelectric/electrostrictive film 76 is restored to its original

state, and thus the thin-walled portion 77 returns to an ordinary state (a flat shape). As a result, the right-hand first working fluid 14b assumes a relatively long, single fluid mass, which simultaneously covers the electrode portions 72b1 and 72c1. Accordingly, the electrodes 72b and 72c are in an electrically connected state.

Subsequently, application of voltage between the upper and lower electrodes of the piezoelectric/electrostrictive film 74 is stopped, and voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 76. As a result, the working-fluid moving device 70 returns to the initial state shown in FIG. 9A. Thus is completed description of operation of the working-fluid moving device 70.

As described above, in the initial state, the electrodes 72b and 72a are held in an electrically connected state, and the electrodes 72b and 72c are in an electrically disconnected state. In the changeover state, the electrodes 72b and 72a are in an electrically disconnected state, and the electrodes 72b and 72c are in an electrically connected state. Accordingly, the electrode 72a constitutes a normally closed terminal, and the electrode 72c constitutes a normally open terminal.

As in the case of the working-fluid moving device 50, the working-fluid moving device 70 utilizes a repulsive fore for moving the first working fluid and thus serves as an SPDT switch having all of the advantages, such as high-speed response, of the working-fluid moving device 50.

In the present modified embodiment, in the initial state, voltage must be applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 76. However, the following configuration

may be employed: the piezoelectric/electrostrictive film 76 and the thin-walled portion 77 are formed beforehand in such a manner as to be deformed downward in a bending condition as shown in FIG. 9A when voltage is not applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 76; and in the changeover state, voltage is applied between the upper and lower electrodes of the piezoelectric/electrostrictive film 76, whereby the thin-walled portion 77 is caused to be deformed upward so as to establish the state shown in FIG. 9B.

Modified Embodiment 14:

As in the case of Modified Embodiment 13, Modified Embodiment 14 is a working-fluid moving device in which a plurality of changeover elements are provided on a single (the same) channel. Specifically, as shown in a conceptual plan view of FIG. 11A, a working-fluid moving device 80 according to Modified Embodiment 14 includes a single channel 82; four changeover elements 84-87 formed on the channel 82; electrodes 82a-82f; and a throttle portion 83 which is formed at the center of the channel 82 so as to reduce the cross-sectional area of the channel 82, thereby preventing passage of the first working fluid.

The changeover element 84 is provided between the electrodes 82a and 82b, and the changeover element 85 is provided between the electrodes 82b and 82c. An assembly including the changeover elements 84 and 85 and the electrodes 82a-82c is substantially the same as the working-fluid moving device 70 shown in FIG. 10, and constitutes a single SPDT switch. The changeover element 86 is provided between the electrodes 82d and 82e, and the changeover element 87 is provided

between the electrodes 82e and 82f. An assembly including the changeover elements 86 and 87 and the electrodes 82d-82f is substantially the same as the working-fluid moving device 70, and constitutes a single SPDT switch shown in FIG. 10.

Thus, the working-fluid moving device 80 constitutes two SPDT switches shown in FIG. 11B by use of a single channel 82.

As shown in FIG. 12A, another working-fluid moving device 90 according to Modified Embodiment 14 includes a single channel 92; six changeover elements 93-98 formed on the channel 92; electrodes 92a-92i; and throttle portions 92-1 and 92-2 which are formed in the channel 92 so as to reduce the cross-sectional area of the channel 92, thereby preventing passage of the first working fluid. The electrodes 92a-92i are formed sequentially from left to right in the channel 92 in FIG. 12A. The throttle portions 92-1 and 92-2 are provided between the electrodes 92c and 92d and between the electrodes 92f and 92g, respectively.

The changeover element 93 is provided between the electrodes 92a and 92b, and the changeover element 94 is provided between the electrodes 92b and 92c. An assembly including the changeover elements 93 and 94 and the electrodes 92a-92c is substantially the same as the working-fluid moving device 70 shown in FIG. 10, and constitutes a single SPDT switch. The changeover element 95 is provided between the electrodes 92d and 92e, and the changeover element 96 is provided between the electrodes 92e and 92f. An assembly including the changeover elements 95 and 96 and the electrodes 92d-92f is substantially the same as the working-fluid moving device 70, and constitutes a single SPDT switch. Similarly, the changeover element 97 is provided between

the electrodes 92g and 92h, and the changeover element 98 is provided between the electrodes 92h and 92i. An assembly including the changeover elements 97 and 98 and the electrodes 92g-92i is substantially the same as the working-fluid moving device 70, and constitutes a single SPDT switch.

Thus, the working-fluid moving device 90 constitutes three SPDT switches shown in FIG. 12B by use of a single channel 92.

The above-described working-fluid moving devices 70-90 include, in a single (common) channel, a plurality of electrode portions (terminals whose electrical connection is changed over between an electrically connected state and an electrically disconnected state by means of the first working fluids 14, 14a, 14b) and changeover elements. In other words, each of these devices is a working-fluid moving device wherein at least a pair of terminals are formed such that, before the deformable portion of a channel is deformed, the terminals assume one of an electrically connected state, in which the terminals are electrically connected via the first working fluid, and an electrically disconnected state, and such that, after the deformable portion is deformed to cause movement of the first working fluid, the terminals assume the other of the electrically disconnected state and the electrically connected state and wherein a plurality of terminal connection-state changeover elements (changeover devices) are formed on a single channel, each terminal connection-state changeover element comprising the deformable portion and the paired terminals. This is a switching unit in which a plurality of switches are formed by use of a single channel.

The above-described configuration can achieve a switching function

similar to that achievable by use of a plurality of working-fluid moving devices which are each configured such that a single terminal connection-state changeover element is formed on a single channel. In addition, since the number of channels is reduced, the above-described configuration can reduce trouble, labor, and the like required for filling channels with the first and second working fluids. Also, a single terminal (electrode portion) can be used as a common electrode (e.g., the electrodes 72b, 82b, 82e, 92b, etc.) for two adjacent terminals located on opposite sides of the terminal. In this case, since the number of terminals can be reduced, the cost of the device can be reduced.

Furthermore, in this case, since two or more deformable portions are used, even when at least one deformable portion is held undeformed while all of the other deformable portions are deformed, a change in pressure (a decrease in pressure and/or an increase in pressure) in the channel reduces in magnitude (maximum magnitude) as compared with (such a change becomes equivalent to or less than) that which arises, as a result of deformation of the deformable portion, in a working-fluid moving device configured such that a single changeover device is formed on a single channel.

In the above-described working-fluid moving devices 70, 80, and 90, the housing body 71, 81, or 91 can be said to be configured such that a plurality of deformable portions are formed on a single channel 72, 82, or 92 and such that, when each of the deformable portions is deformed, the first working fluid which is substantially in contact with the inner wall surface of the channel at the deformable portion is moved by means of a repulsive force which the inner wall surface exerts on the first working fluid.

The above-described configuration can achieve a function substantially similar to that achievable by use of a plurality of working-fluid moving devices which are each configured such that a single deformable portion is formed on a single channel. Since the number of channels is reduced, the above-described configuration can reduce trouble, labor, and the like required for filling channels with the first and second working fluids. Also, the number of repetitions of adjusting pressure in a channel can be reduced, the pressure being a factor of determining the moving speed of the first working fluid.

Since two or more deformable portions are used, even when at least one deformable portion is held undeformed while all of the other deformable portions are deformed, a change in pressure (a decrease in pressure and/or an increase in pressure) in the channel can be reduced in magnitude as compared with that which arises, as a result of deformation of the deformable portion, in a working-fluid moving device configured such that a single deformable portion is formed on a single channel.

Modified Embodiment 15:

Modified Embodiment 15 exemplifies application, to a test apparatus, of a working-fluid moving device in which the deformable portions (i.e., changeover elements) described in Modified Embodiment 4 are arranged in matrix array. Specifically, as shown in FIG. 13, a working-fluid moving device 200 (switching unit 200) includes a plurality of working-fluid moving devices 50 arranged in matrix array (in the present modified embodiment, 4 rows x 4 columns).

A pair of terminals of a first device-under-test 201 are connected to connection lines LA and LB serving as rows A and B, respectively. A pair

of terminals of a second device-under-test 202 are connected to connection lines LC and LD serving as rows C and D, respectively. A first signal source 211 and a second signal source 212 are connected to connection lines L1 and L2, respectively, which serve as columns 1 and 2, respectively. A first measuring device 221 and a second measuring device 222 are connected to connection lines L3 and L4, respectively, which serve as columns 3 and 4, respectively.

Each of the working-fluid moving devices 50 is disposed between a signal line of a certain column and a signal line of a certain row. For example, a single working-fluid moving device 50 is disposed between connection line LA of row A and connection line L1 of column 1 and is adapted to change over the electrical-connection state between these connection lines LA and L1. In other words, a single working-fluid moving device 50 is disposed between connection line Ln of row n (n represents A-D) and connection line Lm of column m (m represents 1-4) and is adapted to change over the electrical-connection state between connection line Ln and connection line Lm.

In this configuration, for example, in the case where, while a signal is supplied to the first device-under-test 201 by use of the first signal source 211, the state (output) of the first device-under-test 201 is to be measured by means of the first measuring device 221, the working-fluid moving device 50 of row B column 1 is activated so as to bring connection lines LB and L1 in an electrically connected state, and the working-fluid moving device 50 of row A column 3 is activated so as to bring connection lines LA and L3 in an electrically connected state.

As a result, a signal from the first signal source 211 is supplied to

the first device-under-test 201 via connection line L1, the working-fluid moving device 50 of row B column 1, and connection line LB; and an output from the first device-under-test 201 is supplied to the first measuring device 221 via connection line LA, the working-fluid moving device 50 of row A column 3, and connection line L3.

As described above, the working-fluid moving device 200 of the present modified embodiment serves as a switching unit in which the working-fluid moving devices 50 are arranged in matrix array so as to change over connection lines to be used. Since a working-fluid moving device according to the present invention allows utilization of a ceramic lamination process in fabrication thereof, as in the case of the working-fluid moving device 200, a plurality of switches can be economically formed or fabricated in the same plane. According to the present invention, variations in characteristics (variations in switching performance) are small among a plurality of working-fluid moving devices formed in a single switching unit, and thus a switching unit with high reliability can be provided.

Notably, a switching unit which can perform three-dimensional switching can be configured through arrangement of the above-described switching units (working-fluid moving devices) 200 in layers. In this manner, a switching unit which exhibits a high density level of packing and is reduced in size can be provided at low cost.

Modified Embodiment 16:

Preferably, the above-described embodiments allows checking to see whether or not, in the driven state, the first working fluid 14 is securely moved or separated (split) and whether or not, back in the initial state, split masses of the working fluid 14 are securely integrated into a single fluid

mass. Specifically, in order to allow light to reach the channel from the outside of the housing body, the housing body is partially or entirely formed from a transparent material (translucent material), thereby allowing check for the position and/or state of the first working fluid 14 by use of, for example, an optical position detector such as a laser beam position detector. When the first working fluid 14 is a liquid metal, eddy current which is generated as a result of the liquid metal moving in the electric field is detected, thereby allowing check for the position and/or state of the first working fluid 14. Furthermore, ultrasonics may be used in the following manner: ultrasonic waves are applied to the channel, and their reflected waves are detected, thereby allowing check for the position and/or state of the first working fluid 14.

As described above, the working-fluid moving devices according to the embodiments and modified embodiments of the present invention can move working fluid while exhibiting reduced conversion loss and good response. Notably, the above-described embodiments and modified embodiments can be used in appropriate combination.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the present invention may be practiced otherwise than as specifically described herein.